Evaluations of Alternative Maintenance Structures

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United States Air Force

RAND

PREFACE

The work described in this report was done at the request of the Commander, Tactical Air Command (TAC). The question of interest was whether TAC should implement an alternative maintenance structure for the avionics maintenance support of certain later versions of its F-16C/D aircraft. A demonstration was conducted at the request of Headquarters, TAC by the Ogden Air Logistics Center, Hill Air Force Base (AFB), Utah; the 388th Tactical Fighter Wing, Hill AFB, Utah; and the 363rd Tactical Fighter Wing, Shaw AFB, South Carolina. The demonstration began on 1 July 1991 and concluded on 1 March 1992. It involved the cessation of intermediate-level repair of avionics components at the two fighter wings and the relocation of test stations and personnel to the Ogden Air Logistics Center. During the demonstration, extensive data were collected to help with evaluation of the demonstration.

RAND participated in the demonstration on an advisory basis to ensure that sufficient data were collected to perform a useful evaluation. In the course of this involvement, RAND used some spares requirements estimation and capability assessment software it had developed in earlier research to estimate the impacts of this new support strategy on spares costs, test stand requirements, and system performance. This report describes those evaluations and offers some important observations, suggestions, and recommendations to the Air Force that may illuminate its decisions about support structure.

This research was done in the Resource Management and System Acquisition Program of Project AIR FORCE.

This report should be of interest to logisticians throughout the Department of Defense, especially those in the Air Force.

SUMMARY

On 1 July 1991, the Tactical Air Command (TAC) and Air Force Logistics Command (AFLC) began a demonstration of a two-levels-of-maintenance concept for avionics. The 388th Tactical Fighter Wing (TFW) at Hill Air Force Base (AFB) repositioned its automated avionics test stations from its own maintenance shop to the avionics maintenance facility of the Ogden Air Logistics Center (ALC), also at Hill AFB. The demonstration was expanded on 1 October by the addition of the 363rd TFW at Shaw AFB, South Carolina. Special data collection was implemented to augment the data collected in standard systems to support the evaluation of the concept. The Commander, TAC asked RAND to assist the Air Force in this effort. We advised those involved in the management of the demonstration on matters of data collection, but, more importantly, we also conducted our own evaluations of these alternative maintenance structures using a system of software we had built for a previous study. We added a regional repair concept to the traditional three-levels and two-levels concepts for the evaluations.

The scenario specified for the evaluations included 403 F-16C/D aircraft of block 40 and later configurations at eight bases. For each alternative avionics maintenance structure, we specified four cases: The third case includes the second, and the fourth includes the second and third.

- *Past performance,* that is, with demand rates, not repairable this station (NRTS) rates, and pipeline times as observed in the current system prior to the start of the demonstration.
- *Expedited handling,* a case in which the high-demand and most expensive LRUs (line-replaceable units) received priority treatment in the system in terms of expedited processing, premium transportation, etc.
- *Improved processes* in depot repair, including priority repair, asset handling, improved awaiting parts (AWP) procedures, improved material support using proactive SRU (shop-replaceable unit) repair,[1] and improved repair parts issue procedures.

[1]The term *proactive SRU repair* describes the application of an algorithm called DRIVE (Distribution and Repair in Variable Environments) that prioritizes repair to maximize the probability of achieving specified aircraft availability goals. In its prioritization, DRIVE specifies the repair of a mix of SRUs intended to support the

- *Improved demand,* such as might result from improved fault diagnosis and elimination of "bad actor" components.

We estimated test station and recoverable spares requirements under each of the four cases and each maintenance structure, three levels, two levels, and regional.

TEST STATION REQUIREMENTS

Figure S.1 shows the number of test stations for each of the three maintenance structures. These numbers are sufficient to ensure little or no queuing of repairable assets due to lack of test station capacity. If the status of the procurement contract for the additional test stations not yet delivered to the Air Force is such that cost avoidance is possible, substantial savings in test station costs might be achieved through implementation of two levels of maintenance for these aircraft. The four types of test stations are coded in the legend, CI for

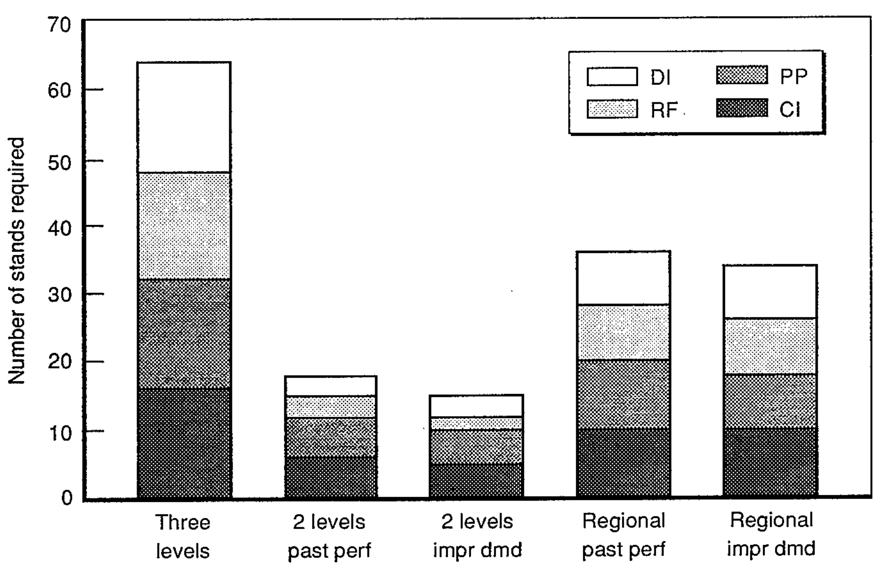

Figure S.1—Test Station Requirements

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repair of LRUs in the succeeding two-week production period, thus increasing the throughput capacity of the LRU repair activity.

computer-inertial, PP for pneumatic-processors, RF for radio frequency, and DI for displays and instruments.

Figure S.2 shows the results of our evaluations of these four cases under each maintenance structure. These results reflect our approach of computing the spares mix for each case individually, using an aircraft availability goal of 94 percent.[2] The height of the bars in Figure S.2 reflects the cost of the mix of spares required for each case. The estimated availability that would be achieved in each case is shown numerically at the top of each bar. Note the greater sensitivity of spares costs to the several management initiatives under the two-levels concept. With all of the initiatives in place, spares costs are reduced to roughly the same as those in the three-levels case. This sensitivity has an important implication for the logistics system. If a two-levels-of-maintenance concept is adopted, depot repair must be responsive to the current and evolving needs of the combat force. By responsive, we mean relevant, timely, and robust. The depot should meet its availability goals, do it in a timely manner, and adopt policies and procedures that enhance its robustness in the face of the va-

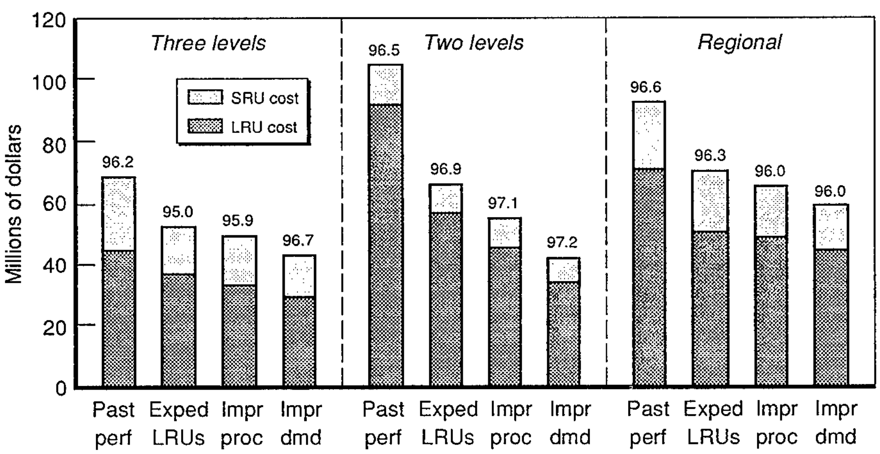
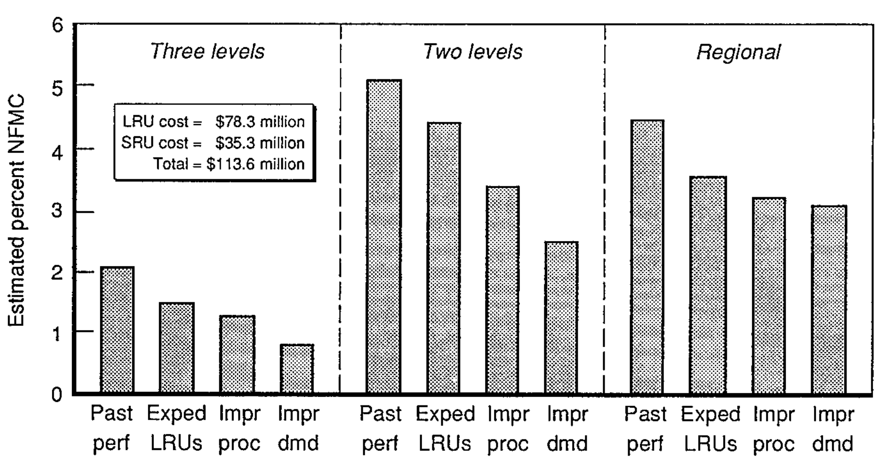


Figure S.2—Spares Costs and Estimated Aircraft Availability

[2]AFLC traditionally specifies an 83 percent availability goal for the F-16 in computing requirements for which we judged intuitively that a 94 percent goal for this small set of avionics LRUs was roughly equivalent. It is unrelated to the 7 percent total nonmission-capable-for-supply standard specified by the Tactical Air Forces (TAF TNMCS) for the F-16.

garies of repair parts demands and repairable carcass generations. Moreover, each segment of the depot pipeline must also be responsive: retrograde, processing, handling, transportation, etc. *Responsiveness is an essential condition for a successful implementation of two levels of maintenance.*

An important issue in this policy analysis is whether a move to a two-levels concept will require substantial additional investments in spares. Figure S.3 shows our estimates of system performance associated with a stockage posture computed with AFLC's D041 (Recoverable Consumption Item Requirements System) spares requirements computation. We used the pipeline times from the D041 database and assumed a three-levels structure. Note that the investment level that results from this computation, $113.6 million, is substantially higher than the cost of the tailored mix of spares computed for the three-levels "past performance" case shown in Figure S.2. This is due to the use of the pipeline times in the D041 database, some of which are surprisingly high compared to those reflected in Appendix A, Table A.1, which were used to compute the stockage underlying Figure S.2. These high values may be associated with the



NOTE: Estimates based on a D041 spares buy for three levels.

Figure S.3—Performance and Spares Cost Using D041 Spares Stockage

extensive use of contract repair for many of these items. In every case, 94 percent or higher availability is achieved.

In a transition to two levels of maintenance, initiatives to enhance the minor repair and troubleshooting capabilities of organizational-level maintenance technicians could be important in minimizing the number of components that are removed from aircraft, sent to the depot for repair, and subsequently judged to be serviceable. For example, it might be helpful to perform a functional check of removed components in another aircraft or on a test station that provides some minimal functional check capability. Reseating circuit cards, replacing such consumables as fuses, light bulbs, and knobs, and performing other minor maintenance well within the capability at base level could appreciably reduce the number of components returned to the depot.

COST CONSIDERATIONS

RAND was not involved in the estimation of costs in these analyses, only in test station and recoverable spares requirements. In their joint final report on Coronet Deuce, TAC and AFLC estimated that a transition to two levels of maintenance with the improved processes in place would reduce personnel requirements by 137 personnel and annual operating and support costs by $6.3 million, but that it would cost about $17 million to move to the two-levels concept because of the costs of additional spares, facility modifications, personnel training, personnel relocations, etc. About $14 million of this cost is for additional LRUs and SRUs to support the two-levels configuration, an estimate that we judge to be too high because it does not account for assets actually on hand in the inventory system or due in from past procurement actions. It seems unlikely, given the outcomes portrayed in Figure S.3, that any substantial additional investment in spares is required.

The other major cost factor in this decision problem is one of cost avoidance. The Air Force estimates that costs incurred by canceling the procurement of the additional test stations now on contract would be "extremely high." On the other hand, an estimated $184 million of undelivered goods and services remain on this contract; thus it is an issue of importance that needs to be resolved to understand fully the cost-reduction opportunities in a transition to two levels of maintenance. Clearly, it is a cost-effective policy alternative, given appropriate levels of system responsiveness.

WARTIME CAPABILITY

Although this work addressed peacetime conditions, we judge that the test station capacities shown in Figure S.1 are sufficient for wartime simply because they were computed with the assumption that they would be manned 80 hours per week. This leaves 88 hours per week of additional capacity (obviously both of these numbers have to be reduced by the mission-capable rates of the test stations). The F-16 war readiness spares kit (WRSK) is presently configured for 30 days of wartime operation without the use of test stations at unit level. The quantity of depot-level test equipment indicated here for two levels of maintenance would provide for the deployment of a set in a combat contingency, if so desired. Experience in Operation Desert Shield/ Storm (ODS) suggests that sufficient retrograde and serviceable shipment capacity was available to make a two-levels concept viable even in wartime. One important problem in a deployment contingency will be to prioritize retrograde shipments and other segments of the depot repair pipeline sensibly. In ODS, retrograde did not receive adequate emphasis.

CONCLUSIONS

We conclude from these analyses that given

- relevant, timely, and robust depot-level component repair,
- responsive depot repair turnaround times prioritized to meet specified aircraft availability goals, and
- repair requirements tied to availability goals and current and evolving asset positions,

both two levels and regional repair are more cost-effective than the traditional three levels of maintenance, even when spares are bought based on the assumptions associated with three levels of maintenance.

The characteristics of components of the F-16A/B and pre-block-40 F-16C/D aircraft are sufficiently similar to those of the block 40 F-16C/D that these findings can be safely extended to the entire F-16 force. In fact, since there are many smaller units equipped with F-16A/B aircraft in the Air National Guard and Air Force Reserve that are authorized only a single string of avionics test stations, a two-levels concept makes even more sense for the F-16A/B than for the later models. Owing to the opportunities for cannibalization across test stations when a unit has more than one string, there may be an even greater payoff associated with a two-levels concept for the remainder of the F-16 force than with the block 40 and later F-16C/D aircraft.

RECOMMENDATIONS

We recommend that the Air Force:

- Establish an aggressive and continuing program to enhance the responsiveness of depot component repair and the management of all segments of the depot repair pipeline, and couple those functions more closely to the combat force.
- Implement a two-levels concept for F-16 avionics (not just the F-16C/D block 40 and later).
- Extend these analyses to determine the cost-effectiveness of the two-levels option for:
  - Other weapon systems.
  - Other commodities, especially engines and other end items.
- Enhance the ability of organizational-level technicians to identify serviceable and repairable components correctly by training them in minor maintenance and functional check procedures to minimize the number of components sent to the depot for repair that are subsequently judged to be serviceable.

ACKNOWLEDGMENTS

The authors are indebted to their RAND colleagues: Karen E. Isaacson, who skillfully carried out the analyses presented in this report; Frederick W. Finnegan, for his patient construction of many of the required data files; and Kenneth J. Girardini and Christopher L. Tsai, for their thoughtful and constructive reviews of the draft manuscript. At the Ogden Air Logistics Center, Kenneth Hales provided the data describing the F-16 components included in the analysis. Maurice Carter, Shane Holbrook, and Russell Koefed also provided valuable support. David Heywood graciously shared his expertise with us to help us understand the details and difficulty of the estimations of costs involved in the two-levels demonstration.

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1. INTRODUCTION

In this report, we examine issues related to the structure and support strategy for avionics maintenance in the Air Force. In particular, the Tactical Air Command (TAC) recently directed that a demonstration be conducted of an alternative to the traditional three-level avionics maintenance support structure involving the relocation of the intermediate level of maintenance from the base to the depot. Two tactical fighter wings, the 388th at Hill Air Force Base (AFB) and 363rd at Shaw AFB, and three air logistics centers (ALCs), Ogden, Warner-Robbins, and San Antonio, participated in the demonstration. It began on 1 July 1991 and concluded on 1 March 1992. It was named Coronet Deuce.

SOME BASIC IDEAS

In the traditional maintenance structure, there are three *echelons* or *levels* of maintenance: organizational, intermediate, and depot. Avionics systems are designed to be modular in the sense that most of their components are readily removable and interchangeable. When a malfunction is observed in the system, it is sometimes corrected through alignment, adjustment, or minor repair on the aircraft (organizational maintenance). Usually, though, components of the system called LRUs (line-replaceable units) are removed from the aircraft and replaced with units that are judged to be *serviceable,* i.e., in good working order. The *repairable* component that is suspected of being defective is delivered to intermediate-level maintenance for fault isolation, repair, and return to serviceable stock or reinstallation in the aircraft. If no serviceable spare is available, the aircraft may have to wait for the repair to be completed and the LRU reinstalled. If the repair of the LRU is beyond the capability of the AIS (avionics intermediate shop, the intermediate level of maintenance for avionics components) or repair is not authorized at the intermediate level, the repairable asset is declared NRTS (not repairable this station) and returned to the depot level (either an AFLC [Air Force Logistics Command] repair center or a contractor facility) for repair. The base then requests a serviceable replacement from the air logistics center (commonly referred to as the depot in the Air Force).

In the two-level alternative to this traditional support arrangement, the intermediate level of repair is eliminated. Components suspected of being defective are removed from aircraft and shipped directly to the depot-level repair activity for fault isolation, repair, and return to the supply system. With only two levels of maintenance, the expected number of LRUs in resupply (i.e., in retrograde shipment from the base to the depot-level repair activity, in repair at the depot or a contract repair facility, in shipment from the depot level back to the base, or in the condemnation pipeline) will be greater than with three levels. A significant proportion of LRUs removed from aircraft are judged to be serviceable when they undergo fault detection procedures and no defect is found. Under the traditional three-levels concept, after undergoing evaluation in the AIS, these LRUs are returned to stock or reinstalled in an aircraft; under a two-levels concept, since they cannot be tested at intermediate level, they will be declared NRTS and added to the depot repair pipeline. The proportion of LRUs removed from aircraft in the belief they are defective that subsequently are judged serviceable after fault isolation procedures varies by weapon system, of course, but tends to be roughly 30 percent, or somewhat less in modern fighter aircraft such as the F-15 and F-16. The expected number of components in this category is commonly referred to as the BCS pipeline (BCS for bench check serviceable).

We also evaluate a regional repair concept here. In this concept, the intermediate level of maintenance is not eliminated; rather, intermediate-level repair is consolidated at fewer bases, and those bases support the repair requirements of other bases in their regions. The idea underlying this maintenance concept is that most of the available economies of scale can be achieved while possibly keeping pipelines shorter than if the depot repair system is the sole source of repair. The notion that repair turnaround times (which we define as the total elapsed time from component removal from the aircraft until repair and return to serviceable condition) would be significantly different in the regional structure from those in the two-levels structure is probably rooted in the depot repair turnaround times frequently observed in the traditional three-levels structure. There are, in short, some remarkably long depot repair turnaround times reflected in the spares requirements database the Air Force maintains to support its estimations of requirements for recoverable spares and depot-level repair. They give one pause to reflect on the feasibility of relying on the depot repair system to support component repairs responsively enough to make the two-levels concept viable. Thus the issue of responsiveness in depot-level component repair and in each segment of the depot repair pipeline (retrograde, handling and processing, prioritization, repair, and transportation of the serviceable assets) is a major one for the cost-effectiveness of two levels of maintenance.

IMPORTANT FACTORS IN DETERMINING MAINTENANCE CONCEPT

The increase in the size of the BCS pipeline to the depot owing to the elimination of the intermediate level of maintenance is one of the principal issues involved in the policy decision being examined here. Another major issue in this context is that since base repair turnaround times are typically much shorter than depot repair turnaround times owing to the additional processing, handling, and transportation involved in depot repair, eliminating the intermediate level of maintenance results in larger numbers of components experiencing the longer repair turnaround times associated with traditional depot-level repair. As we will point out in later discussion, it is vital to a successful implementation of a two-levels-of-maintenance concept that the depot repair turnaround time be kept as short as practicality allows, and that the logistics system give highest priority in processing, handling, transportation, and repair to the components that are most urgently needed by the combat force to achieve its aircraft availability goals. As we will show, *responsive depot repair turnaround times are an absolute prerequisite for a cost-effective two-levels concept.*

The two-levels concept is attractive because of economies of scale in the numbers of test stands and maintenance personnel required to support the repair workload. There are also substantial support costs associated with test stands. On the other hand, the two-levels concept has higher spares and transportation costs than the traditional structure, and it depends heavily on system responsiveness to be truly cost-effective. These important factors are examined and quantified in this report.

A move to two levels of maintenance raises some important questions about organizational maintenance practices and procedures as well. To minimize the number of LRUs sent back to the depot for repair and subsequently judged to be serviceable, organizational maintenance technicians could be provided with additional training in procedures that would help them judge the serviceability of a component removed from an aircraft. Such procedures might include functionally checking the LRU in another aircraft, reseating circuit cards, checking for obvious damage, making minor adjustments, replacing parts that are obviously defective and within the capability of the organizational level (e.g., light bulbs, fuses, knobs), repairing connectors, etc. Some of the test equipment the Air Force currently plans to procure for base-level maintenance is much more modest in scope, capability, and cost than the AIS test equipment; it could also be helpful in minimizing the size of the BCS pipeline.

Given responsive depot repair turnaround times, the Coronet Deuce demonstration and the evaluations discussed in this report support the conclusion that the concept of two levels of maintenance is more cost-effective than either the regional repair concept or the traditional three-levels structure for the F-16 force. Although the scope of Coronet Deuce was limited to the block 40 and later F-16C/D aircraft, our conclusions extend directly to their earlier cousins, for reasons we will discuss later. The regional arrangement is also more cost-effective than the traditional three levels of maintenance.

RESULTS OF PREVIOUS STUDIES

This finding is consistent with a RAND study done several years ago involving avionics support of the F-15 aircraft.[1] Although it did not explicitly evaluate a two-levels concept, the study found that consolidation of test stations at very few locations provided better support at less cost than the deployment planned at the time. In its Uncertainty Project, RAND also evaluated a consolidated intermediate maintenance concept and found it more cost-effective in the F-16 case as well.[2] Although these studies were concerned with performance in a NATO wartime scenario, the major factors of the problem extend to peacetime operations as well, as we show in Section 3.

Similar observations have been made in the Army case for high-technology subsystems. Berman et al.[3] concluded that consolidating test equipment at the main support battalion, rather than at the lower-echelon forward support battalion, improved the availability of test equipment for items that most affect the combat capability of the M1 tank and permitted the assessment of repair priorities across three brigades, thus increasing tank combat availability. Wild[4] reached a similar conclusion where test equipment was used to repair components from more than one weapon system, in particular the M1 tank and the M2/M3 Bradley Fighting Vehicle. Robbins et al. [5] contrasted

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[1]Based on past RAND research conducted by H. L. Shulman and Jean B. Gebman.

[2]Unpublished work by Thomas F. Lippiatt of RAND.

[3]Berman, Morton B., et al., *Evaluating the Combat Payoff of Alternative Logistics Structures for High-Technology Subsystems,* RAND, R-3673-A, October 1988.

[4]Wild, William G., Jr., *Supporting Combined-Arms Combat Capability with Shared Electronic Maintenance Facilities,* RAND, R-3793-A, May 1990.

[5]Robbins, Marc L., et al., *Developing Robust Support Structures for High-Technology Subsystems: The AH-64 Apache Helicopter,* RAND, R-3768-A, 1991.

the cost and performance of the Army's current support system for the AH-64 helicopter with those of more responsive support structures involving lower investments in spares and greater emphasis on system responsiveness. He concluded that the more responsive options delivered equal performance at 40 to 45 percent less cost. Moreover, he found the performance of the more responsive options more robust in the face of wartime uncertainties.

WHAT FOLLOWS

In Section 2, we describe our approach to the evaluations, including a description of the alternatives we examined, the associated scenarios for the F-16C/D block 40 and later aircraft, our assumptions and approach, and caveats about the models we used. We present and discuss our results in Section 3 and offer our conclusions and recommendations in Section 4. The pipeline times used in the analyses can be found in Appendix A.

2. DESCRIPTION OF EVALUATIONS

We evaluated three alternative logistics structures: the traditional three levels of maintenance, two levels, and regional repair. Two configurations of the regional repair case were examined. We will describe both of them, but since the performances of the two cases were essentially the same, we will focus on only one of them.

For each alternative maintenance structure, we analyzed four cases. The third case includes the second; the fourth includes the second and third, as follows:

- *Past performance,* that is with demand rates, NRTS rates, and pipeline times as observed in the current system.
- *Expedited handling,* a case in which the highest demand and most expensive LRUs received priority treatment in the system in terms of expedited processing, premium transportation, etc.
- *Improved processes* in depot repair, including priority repair, asset handling, improved AWP procedures, improved material support using proactive SRU (shop-replaceable unit) repair,[1] and improved repair parts issue procedures.
- *Improved demand,* such as might result from improved fault diagnosis and elimination of "bad actor" components.

EVALUATION SCENARIOS

The evaluations included 403 F-16C/D aircraft, block 40 and later, at eight bases: Eielson AFB, Alaska; Hill AFB, Utah; Luke AFB, Arizona; Moody AFB, Georgia; Mountain Home AFB, Idaho; Nellis AFB, Nevada; Osan AB, Republic of Korea; and Shaw AFB, South Carolina. The four scenarios used are described in Tables 2.1 through 2.3.

Table 2.1 reflects the currently planned structure, a traditional three-levels-of-maintenance concept for avionics with the exception that the

[1]The term *proactive SRU repair* describes the application of an algorithm called DRIVE (Distribution and Repair in Variable Environments) that prioritizes repair to maximize the probability of achieving specified aircraft availability goals. In its prioritization, DRIVE specifies the repair of a mix of SRUs intended to support the repair of LRUs in the next subsequent two-week production period, thus increasing the throughput capacity of the LRU repair activity.

Table 2.1

Three Levels as Planned

Base	I-Level Maint	Regional Repair
Eielson AFB	X	
Hill AFB	X	
Luke AFB	X	
Moody AFB	X	
Mountain Home AFB		
Nellis AFB	X	X
Osan AB	X	
Shaw AFB	X	

composite wing at Mountain Home AFB is supported by intermediate-level (I-level) maintenance at Nellis AFB; thus Nellis is not a regional repair center in the usual sense because it supports only itself and Mountain Home.

The two-levels scenario is straightforward; the Ogden ALC at Hill AFB performs all repairs for all bases, even Osan and Eielson. Incoming repairable components are screened on automated test stations and either declared serviceable, repaired, sent to a contractor for repair, or sent to a special repair activity if their history suggests the special characteristics of a "bad actor."

We evaluated two regional repair arrangements that are described in Tables 2.2 and 2.3. In the first, described in Table 2.2, Hill and Moody are regional repair centers. Note that Osan and Eielson keep their intermediate repair capability but only for their own support. In the second case, described in Table 2.3, Luke and Shaw are the

Table 2.2

Regional Repair Structure, Case 1

Base	I-Level Maint	Regional Repair
Eielson AFB	X	
Hill AFB	X	X
Luke AFB		
Moody AFB	X	X
Mountain Home AFB		
Nellis AFB		
Osan AB	X	
Shaw AFB		

Table 2.3

Regional Repair Structure, Case 2

Base	I-Level Maint	Regional Repair
Eielson AFB	X	
Hill AFB		
Luke AFB	X	X
Moody AFB		
Mountain Home AFB		
Nellis AFB		
Osan AB	X	
Shaw AFB	X	X

regional repair centers and, again, Osan and Eielson keep their intermediate capability. The costs and performance in these two cases were essentially the same. In our discussions of regional repair, the regional repair case refers to either of these particular arrangements.

ASSUMPTIONS AND CONDITIONS

Our evaluations were constrained in scope to include recoverable spares, pipeline quantities, and test stations required. Manpower, transportation, and test station costs are being estimated by Ogden. We evaluated each case under two different spares assumptions:

- *Assumption 1.* Spares requirements are computed from scratch, i.e., assuming that there is no stock in the inventory system, using AFLC's current spares requirements computational methods and a 94 percent aircraft availability goal.[2] Thus, we hold aircraft availability roughly constant and compute the spares mix required for each case.
- *Assumption 2.* Spares requirements are computed as though we are buying spares to support the traditional three-levels structure using pipeline times from the D041 database that AFLC uses to compute spares requirements. With this assumption, we estimate aircraft availability for each alternative structure with the same "three-levels" spares mix.

[2]AFLC traditionally specifies an 83 percent availability goal in computing spares requirements for the F-16. We judged intuitively that a goal of 94 percent for this limited set of LRUs would be roughly equivalent. It is unrelated to the total non-mission-capable-for-supply standard specified by the Tactical Air Forces (TAF TNMCS) of 7 percent.

The reason for using the three-levels spares mix under Assumption 2 is that the Air Force has already purchased spares assuming a three-levels structure. The pipeline times used for each scenario under Assumption 1 are shown in Appendix A.

APPROACH TO EVALUATIONS

We used the system of software illustrated in Figure 2.1 to compute the spares requirements and perform the evaluations in this work. This software replicates the computations of the CSIS (AFLC's Central Secondary Item Stratification, which computes recoverable spares and repair requirements) and the Aircraft Availability Model (AAM) that is imbedded in D041 (the Recoverable Consumption Item Requirements System) to compute requirements for safety stock. It also replicates AFLC's central stock-leveling system, D028, in allocating the POS[3] levels to individual bases and the depot. The stock levels, along with scenario characteristics, are then fed to Dyna-METRIC Version 6, which evaluates system performance in terms of the aircraft availability delivered by the stockage posture that results

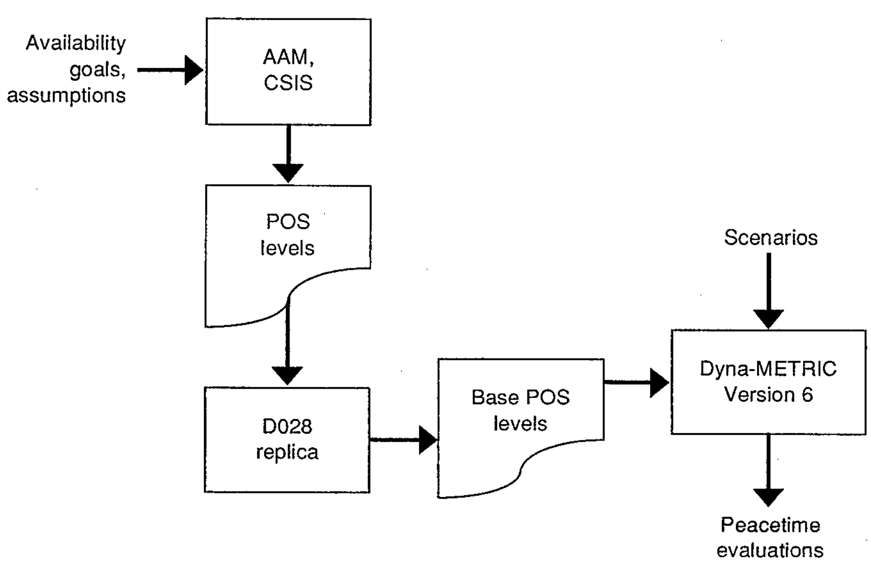


Figure 2.1—Approach to Evaluations

[3]Primary operating stock, formerly known as peacetime operating stock.

from the spares requirements computation and stock-leveling procedure.

There are inconsistencies in this system of models, particularly between the Aircraft Availability Model and Dyna-METRIC. Table 2.4 reflects the principal differences. These differences tend to result in higher aircraft availabilities being estimated by Dyna-METRIC than are specified to the spares requirements computation. The higher availabilities are more representative of actual field experience.

Table 2.4

Differences in Modeling Assumptions

Aircraft Availability Model	Dyna-METRIC Version 6
No cannibalization	Full cannibalization
No lateral supply	Lateral supply
Average base assumption	Actual force beddown

3. RESULTS OF EVALUATIONS

This section comprises two discussions, one relating to test station requirements and one to the costs and performance of the alternative maintenance structures under the various assumptions and conditions described in Section 2.

TEST STATION REQUIREMENTS

Figure 3.1 reflects the test station requirements for each of the three alternative maintenance structures. Note that when demand functions are reduced through effective repair of bad actors and improved fault isolation techniques, test station requirements are reduced somewhat, but not substantially. The structural differences have far more dramatic effects on test station requirements. As we will see in the discussion of system performance, though, improving demand functions pays off.

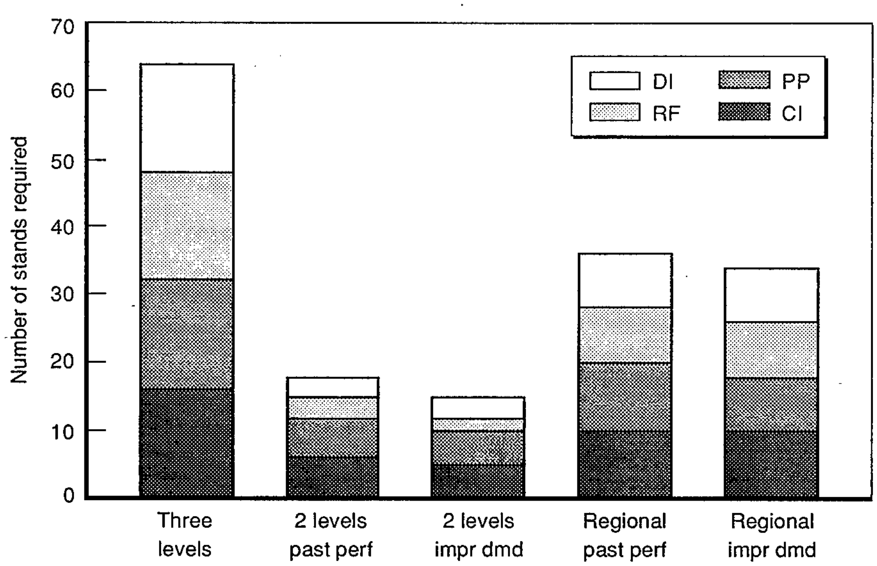


Figure 3.1—Test Station Requirements

The differences in test station requirements associated with alternative maintenance structures are, indeed, dramatic: 64 test stations in the traditional three-levels case, 36 in the regional case, and only 18 in the two-levels arrangement. Note that in the two-levels and regional cases, there may be different numbers of each type of test station required, CI (computer-inertial), PP (pneumatic-processors), RF (radio frequency), and DI (displays and instruments). The greater the level of consolidation, the more likely the number of stations of each type will differ owing to the generally reduced effect of rounding error in the computation of the required number of test stations.

In the three-levels structure, 16 strings of test stations are required, including 2 strings at the depot. Other locations would have 2 strings each except Osan and Eielson, which have 1 string each. With the regional repair concept, each regional repair center would have three CI, three PP, two RF, and two DI stations. The eastern center would support 198 aircraft, and the western, 157. Osan and Eielson would each have 1 string to support 24 aircraft, and the depot would have 2 strings.

In determining the requirements shown in Figure 3.1, we made initial estimates based on the number of aircraft supported, the flying hour program, LRU removal rates (including BCS actions), test station time required per LRU of each type, and test station availability rates. We also accounted explicitly for the increase in test station availability as a function of the number of collocated test stations associated with each scenario. As we mentioned previously, we assured ourselves that these test station requirements were sufficient by specifying them to Dyna-METRIC and observing little or no queuing of repairable components. We judge that the test station requirements are sufficient for wartime as well because we assume that they are manned for only 80 hours per week in peacetime, leaving 88 hours per week of additional capacity (we discounted these capacities by test station availability rates, of course). The substantial reduction in the total number of test stations in the system is possible because:

- Test stations at intermediate level are only modestly utilized at the present time,
- Consolidation of two or more test stations at a single location enables cannibalization actions across test stations, thus raising the overall level of mission capability of the test stations, and
- The effects of rounding error are reduced.

These test station requirements are less than the number of test stations already on hand. The requirements are tied to the planned force beddown and, of course, to the maintenance structure. Whether substantial savings are available in the two-levels and regional cases depends on the status of the test station acquisition contract, i.e., on whether some test station procurements can be canceled, and on the cancellation costs. We discuss these cost issues further in Section 4.

There may be productive uses for test stations that turn out to be in excess of the requirements for the specific maintenance structure eventually selected by the Air Force for this weapon system. For example, some could provide a mobile test capability for safety-of-flight technical order compliance. They could be a source of spare parts for operational test stations or even provide a kind of floating stock to cover programmed depot maintenance of operational stations, as well as assets for foreign military sales.

Fewer test stations imply the need for less manpower, less calibration, less repair, and less programmed depot maintenance. The cost reductions are significant: $293,000 annually per test station.[1] Excluding manpower costs, the difference in operating and support costs for the test stations alone between three levels and two is over $13 million annually, even without improved demand functions.

COSTS AND PERFORMANCE OF ALTERNATIVE MAINTENANCE STRUCTURES

Figure 3.2 reflects the results of our evaluations of the three alternative maintenance structures under Assumption 1, that is, where we computed spares stockage requirements from scratch for each case. The number above each bar shows the aircraft availability achieved in that particular case as estimated by the capability assessment model, Dyna-METRIC Version 6; the differences among these numbers are largely attributable to experimental error; i.e., an aircraft availability goal of 94 percent was specified in all of these cases. The fact that they are all above 94 percent is due to the differences in assumptions made by the spares requirements and distribution software and the capability assessment software (see Table 2.4). The height of each bar reflects the costs of recoverable LRUs and

[1]Estimated in "Cost Benefit Analysis on F-16 Block 40 Aircraft Two-Level Maintenance," Attachment 7, incorporated in *Coronet Deuce: F-16 Block 40 Avionics Maintenance Test,* published jointly by the Tactical Air Command and the Air Force Logistics Command, 10 March 1992.

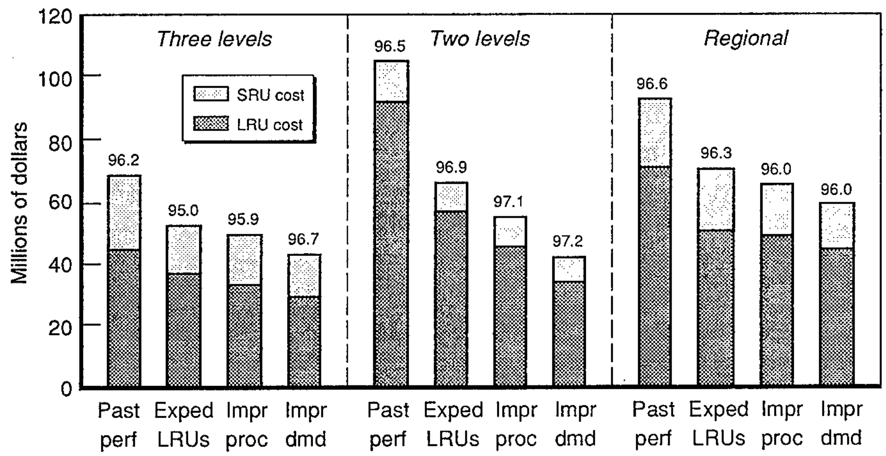


Figure 3.2—Spares Costs and Estimated Aircraft Availability

SRUs in the stockage posture computed in that case. For the "past performance" case, the cost of spares for the two-levels concept is the highest, and the regional concept is the next most costly.

Another important observation can be made about these data. In the traditional three-levels-of-maintenance structure, the initiatives of expedited handling, improved depot repair responsiveness, and improved demand functions have less payoff in spares cost reductions, given roughly constant aircraft availability. In the two-levels case, however, the payoffs of these initiatives are substantially greater. In other words, the two-levels arrangement is much more sensitive to the initiatives than is the three-levels case. Note that when all three initiatives are in place, spares costs between the two-levels and three-levels cases are essentially the same, although the two-levels mix favors heavier investments in LRUs. If the depot is not responsive, however, as shown in the "past performance" cases, $36.2 million more in spares investments is required to maintain approximately the same aircraft availability.

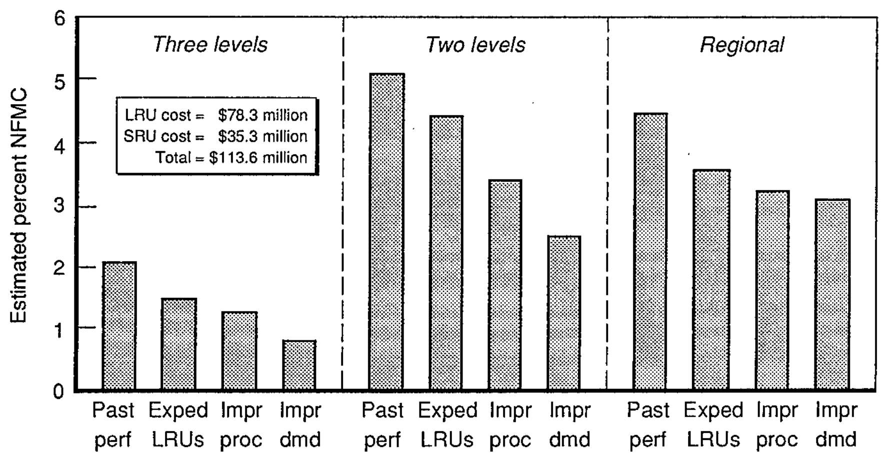
This conclusion is compelling. *Two levels of maintenance could be the most cost-effective maintenance structure for these aircraft, but only if the depot component repair system is sufficiently responsive to obviate the need for the much greater investments in spares that would be required with current depot repair pipeline times.* If the depot's performance stays the same as it was before the start of Coronet Deuce, system performance would suffer under a two-levels concept unless sufficient spares were available to fill the longer pipelines. Thus, the effectiveness of the two-levels-of-maintenance concept depends heavily on AFLC's motivation and ability to achieve genuinely relevant, timely, and robust depot-level component repair. It implies a change in management orientation in depot maintenance as well as a need for decision support mechanisms that will couple the depot repair system more closely to the combat force. It implies, too, the need for responsiveness in all segments of the depot repair pipeline.

COSTS AND PERFORMANCE USING D041 SPARES STOCKAGE FOR THREE LEVELS

An important question facing the Air Force in this policy decision is whether substantial additional investments in spares will be required to support an implementation of the two-levels concept. Figure 3.3 shows the results of using the Air Force's standard spares requirements estimation system (D041) to compute requirements for the three-levels case. Note that it estimates budgetary requirements substantially greater than those shown in Figure 3.2. It also suggests that if the spares requirement is bought for a three-levels concept, even though the mix of spares is not tailored specifically to the two-levels structure, system performance under a two-levels concept will be satisfactory. As before, the management initiatives pay off even in the face of this substantially greater spares investment, although they are less interesting because of the greater richness of the spares posture.

In Figure 3.3, the spares stockage was computed using the Air Force's current spares requirements determination methods and reflects the item pipeline times contained in the D041 requirements database. Many of these pipeline times are surprisingly long, owing, perhaps, to the past use of contract repair for many of these components. This may account in large part for the much higher investment level than that shown in Figure 3.2 for the "past performance" case under the three-levels concept. We chose this stockage for illustrative purposes because the Air Force has already invested in spares on the assumption of a three-levels posture.

Note that both two levels and regional repair require higher ratios of LRUs to SRUs than does three levels of maintenance. Note, too, that the richer LRU mix that would result from specifying a two-levels or regional structure to the spares requirements computation would be more beneficial in rapid-deployment contingencies.



NOTE: Estimates based on a D041 spares buy for three levels.

Figure 3.3—Performance and Spares Cost Using D041 Spares Stockage

COST CONSIDERATIONS AND POTENTIAL SAVINGS

RAND's involvement in Coronet Deuce did not include estimating costs or cost savings except for recoverable spares; however, our conclusions and recommendations obviously depend on knowledge of cost considerations that we have not yet made visible. We present here some of the cost estimates made by the Air Force in the course of the demonstration.[2]

The *Coronet Deuce* final report published jointly by the Tactical Air Command and the Air Force Logistics Command estimates a net savings of 137 people in a move to two levels of maintenance for these aircraft, as well as $6.3 million in annual operating and support cost savings and an unknown potential savings in test station capital costs. These estimated savings are associated with the "improved processes" cases and account for the additional costs of premium transportation for selected LRUs, higher management costs to achieve pipeline time reductions, etc. Had the Air Force been able to cancel its planned procurement of additional test stations, it could

[2]This discussion draws heavily from *Coronet Deuce F-16 Block 40 Avionics Maintenance Test,* Tactical Air Command and Air Force Logistics Command, 10 March 1992.

have realized a cost avoidance of about $184 million, less the cost of cancellation of the procurement contract. The cancellation cost is unknown, but was estimated to be "extremely high." The report also estimates a one-time cost of about $17 million to change from three levels of maintenance to two levels for additional spares, facility modifications, personnel training, personnel relocations, etc. However, about $14 million of this cost is attributed to additional LRUs and SRUs to support the two-levels configuration, a cost estimate that we believe is much too high because it does not account explicitly for assets actually on hand in the inventory system or due in from past procurement actions. Moreover, given the outcomes portrayed in Figure 3.3, it seems unlikely that any substantial additional spares investments will be required.

The report also estimates a potential revenue of $38.1 million from foreign military sales of test stations. This estimate is based on a sales price substantially lower than procurement cost. Thus the ultimate cost picture is very unclear at this point. What is clear, however, is that despite some one-time costs to move from three levels to two, sufficiently high annual savings show that the two-levels option is clearly less costly in the long run and may yield substantial near-term cost avoidance.

IMPLICATIONS FOR WARTIME

The analysis presented here examined a peacetime scenario. We have not analyzed some issues associated with deployment contingencies. However, we judge that the number of test stands associated with the several cases under each maintenance concept is ample for wartime simply because the test stands are assumed to be manned only 80 hours per week in peacetime, leaving 88 additional hours unused. Obviously, both of these numbers have to be discounted by the test stations' mission-capable rates. In any event, this assumption, coupled with priority repair, more than provides for adequate capacity for wartime activity levels. The mix of avionics components in F-16 WRSKs is computed for 30 days of wartime activity without any avionics test equipment at the unit level.

We do not envision deployment of avionics test stations with F-16 units in a contingency, although the number of test stations suggested in Figure 3.1 provides for the deployment of a set to support a contingency in theater. The wisdom of supporting deployed units from the CONUS depot depends heavily on logisticians in theater assigning appropriate priorities to retrograde assets and moving them promptly. During Operation Desert Shield/Storm (ODS), retrograde capacity was never an issue, but retrograde assets barely moved simply because of lack of priority. Obviously, with a two-levels concept, such a condition is unacceptable. Airlift was available in some form or other throughout ODS for transporting serviceable assets to the theater. Thus, support for a two-levels concept in wartime contingencies seems within reach. The problem will be to ensure that the correct logic is applied to cargo prioritization.

There are other important assumptions about wartime being made throughout these discussions, assumptions about responsiveness in all segments of the depot repair pipeline. During the Coronet Deuce demonstration, Ogden achieved a reduction in the average depot repair turnaround time (from component removal through depot repair) from an average of 30.2 days at the start of the test to 15.7 days in February 1992. Warner-Robbins ALC reduced its average turnaround time from 26.5 to 19 days during the same period. Thus, we are optimistic about the Air Force's ability to resolve these issues of responsiveness, but we have not estimated the costs of achieving acceptable levels of responsiveness ourselves. We simply caution the Air Force that without responsive depot repair, prompt movement of retrograde assets, and intelligently prioritized processing and handling of assets in the depot repair pipeline, a move to two levels of maintenance is fraught with hazards, in peacetime as well as wartime.

4. CONCLUSIONS AND RECOMMENDATIONS

We conclude from these analyses that given

- relevant, timely, and robust depot-level component repair,
- responsive depot repair turnaround times prioritized to meet specified aircraft availability goals, and
- repair requirements tied to availability goals and current and evolving asset positions,

both two levels and regional repair are more cost-effective than the traditional three levels of maintenance. *This is true even when spares are bought based on the assumptions associated with three levels of maintenance.* The key to realizing the improved cost-effectiveness of the two-levels alternative lies in responsive depot-level component repair as well as transportation and handling of assets that are sensibly prioritized to achieve aircraft availability goals.

Cost avoidance opportunities may exist in canceling some planned test station procurements. We do not know, at the time of this writing, whether cancellation is possible or practical. If savings are achievable, they strengthen our conclusions and recommendations.

The failure rates and other characteristics of avionics components of the F-16A/B and F-16C/D pre-block-40 aircraft are quite similar to those in the F-16C/D block 40 and later aircraft, despite some significant improvements in the reliability of specific LRUs. There is no reason to believe that these findings do not apply to the other F-16 aircraft. In fact, units with smaller numbers of aircraft assigned, as many of the F-16A/B Air National Guard and Air Force Reserve units have, could benefit from a move to two levels of maintenance even more than larger units because the smaller units are authorized only a single string of test stations. It is well known that the allocation of two or more strings to a single location results in higher mission-capable rates for the test stands owing to the availability of the second string for parts cannibalization.

Finally, improved performance would be achieved with a spares mix tailored to the actual maintenance structure of the system.

We recommend that the Air Force:

- Establish an aggressive and continuing program to enhance the responsiveness of depot component repair and the management of all segments of the depot repair pipeline and couple those functions more closely to the combat force.
- Implement a two-levels concept for F-16 avionics (not just the F-16C/D block 40 and later).
- Extend these analyses to determine the cost-effectiveness of the two-levels option for:
  - Other weapon systems.
  - Other commodities, especially engines and other end items.
- Enhance the ability of organizational-level technicians to identify serviceable and repairable components correctly by training them in minor maintenance and functional check procedures to minimize the number of components sent to the depot for repair that are subsequently judged to be serviceable.

Appendix
PIPELINE TIMES USED IN THE ANALYSES

In this appendix, we explicate our assumptions about the lengths of the various segments of the pipelines we assumed in the evaluations described in this report. Tables A.1 through A.12 reflect the lengths of each of the pipeline segments, base repair time, depot repair time, and order-and-ship time. We define each of these pipeline segments as follows.

Base repair time (BRT in the tables) is the expected elapsed time between removal of a component from an aircraft and its return to serviceable condition in base supply. Under a regional repair concept, this includes transportation from the base at which the removal occurred to the regional repair activity.

Depot repair time (DRT in the tables) is the expected elapsed time between removal of a component from an aircraft and its return to serviceable condition at the depot. This includes the elapsed time prior to the decision to declare the component NRTS plus the time to ship it to the depot repair facility, process it, induct it into repair, repair it, and return it to serviceable condition in depot supply. In the body of this report, we described this expected elapsed time as the *depot repair turnaround time.*

Order-and-ship time (OST in the tables) is the expected elapsed time from generation of a requisition for an item at a base until receipt of a serviceable asset from the depot or regional repair activity, excluding any delay time owing to lack of a serviceable asset on hand at the depot or regional repair activity.

In the tables that follow, we always assumed base repair times were six days when intermediate-level repair was collocated with the aircraft. "Past performance" data reflect actual Air Force experience. Our assumptions in the "expedited LRUs" cases are consistent with shipping times achieved by such agencies as Federal Express or DHL. In the "improved process" cases, for non-AWP LRUs, repair and processing times reflect the improved performance achieved by the depot during Coronet Deuce, including express table processing for the "expedited LRUs" cases.

To achieve this performance, proactive SRU repair and prioritization of repairs are necessary. There is good reason to believe that sensible prioritization of repair can yield even greater aircraft availabilities than suggested in this analysis.

THREE LEVELS OF MAINTENANCE

Table A.1

Pipeline Times for Past Performance, Nonexpedited LRUs

	Location				
Pipeline Segment	Hill AFB	Mt. Home AFB	Other CONUS Bases	Eielson AFB	Osan AFB
BRT	6	20	6	6	6
DRT	37	53	46	54	60
OST	1	6	6	14	20

Table A.2

Pipeline Times for Past Performance, Expedited LRUs

	Location				
Pipeline Segment	Hill AFB	Mt. Home AFB	Other CONUS Bases	Eielson AFB	Osan AFB
BRT	6	11	6	6	6
DRT	26	32	29	29	29
OST	1	2	2	2	2

Table A.3

Pipeline Times for Improved Process, Nonexpedited LRUs

	Location				
Pipeline Segment	Hill AFB	Mt. Home AFB	Other CONUS Bases	Eielson AFB	Osan AFB
BRT	6	20	6	6	6
DRT	27	43	36	44	50
OST	1	6	6	14	20

Table A.4

Pipeline Times for Improved Process, Expedited LRUs

	Location				
Pipeline Segment	Hill AFB	Mt. Home AFB	Other CONUS Bases	Eielson AFB	Osan AFB
BRT	6	11	6	6	6
DRT	22	28	25	25	25
OST	1	2	2	2	2

TWO LEVELS OF MAINTENANCE

Table A.5

Pipeline Times for Past Performance, Nonexpedited LRUs

	Location			
Pipeline Segment	Hill AFB	Other CONUS Bases	Eielson AFB	Osan AFB
DRT	23	32	40	46
OST	1	6	14	20

Table A.6

Pipeline Times for Past Performance, Expedited LRUs

	Location			
Pipeline Segment	Hill AFB	Other CONUS Bases	Eielson AFB	Osan AFB
DRT	12	15	15	15
OST	1	2	2	2

Table A.7

Pipeline Times for Improved Process, Nonexpedited LRUs

	Location			
Pipeline Segment	Hill AFB	Other CONUS Bases	Eielson AFB	Osan AFB
DRT	13	22	30	36
OST	1	6	14	20

Table A.8

Pipeline Times for Improved Process, Expedited LRUs

	Location			
Pipeline Segment	Hill AFB	Other CONUS Bases	Eielson AFB	Osan AFB
DRT	9	12	12	12
OST	1	2	2	2

REGIONAL REPAIR CONCEPT

Table A.9

Pipeline Times for Past Performance, Nonexpedited LRUs

	Location					
Pipeline Segment	Hill AFB	Moody, Shaw, or Luke AFB	Bases Atchd to Hill	Bases Atchd to Moody/ Shaw/Luke	Eielson AFB	Osan AFB
BRT	6	6	20	20	6	6
DRT	37	46	44	53	54	60
OST	1	6	6	6	14	20

Table A.10

Pipeline Times for Past Performance, Expedited LRUs

	Location					
Pipeline Segment	Hill AFB	Moody, Shaw, or Luke AFB	Bases Atchd to Hill	Bases Atchd to Moody/ Shaw/Luke	Eielson AFB	Osan AFB
BRT	6	6	11	11	6	6
DRT	26	29	29	32	29	29
OST	1	2	2	2	2	2

Table A.11

Pipeline Times for Improved Process, Nonexpedited LRUs

	Location					
Pipeline Segment	Hill AFB	Moody, Shaw, or Luke AFB	Bases Atchd to Hill	Bases Atchd to Moody/ Shaw/Luke	Eielson AFB	Osan AFB
BRT	6	6	11	11	6	6
DRT	27	36	34	43	44	50
OST	1	6	6	6	14	20

Table A.12

Pipeline Times for Improved Process, Expedited LRUs

	Location					
Pipeline Segment	Hill AFB	Moody, Shaw, or Luke AFB	Bases Atchd to Hill	Bases Atchd to Moody/ Shaw/Luke	Eielson AFB	Osan AFB
BRT	6	6	11	11	6	6
DRT	22	25	25	28	25	25
OST	1	2	2	2	2	2

NOTE: The regional arrangement with Hill and Moody as the regional repair centers has essentially the same performance as that with Luke and Shaw as the regional repair centers.

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